NuMI Operating Conditions

NuMI-X Mtg. 8 August., 2014 Jim Hylen / FNAL

Some topics relevant to beam flux calculation

List of dates / changes to beam

Beam

- toroid measurement POT
- **position on target**, BPM non-linearity
- **spot size - variation over time.**
  - **extrapolation from PM121, PMTGT to target**

Windows

- primary beam window
- target windows
- DK upstream and downstream windows

Chase - layout of shielding

Baffle

- geometry
- beam scraping fraction

Target

- **longitudinal for LE targets, & MET-01**
- **transverse alignment - scans, TVPT vs hadmon**
- Next NUMI target will have 3 Be fins
- integrated POT so far, close to nominal change,
  - but no visible degradation, so leave it in

Horn

- **Ar, H2O film & spray in horn**
- **horn current**
- **calibration (include MINOS-doc)**
- **changes with heat**
  - **deliberate change in voltage**
- transverse alignment
- **survey alignment of horn 2**
- fringe fields and current equalization section
- mapping?

Decay pipe

- **helium pressure**
- magnetic field

Absorber

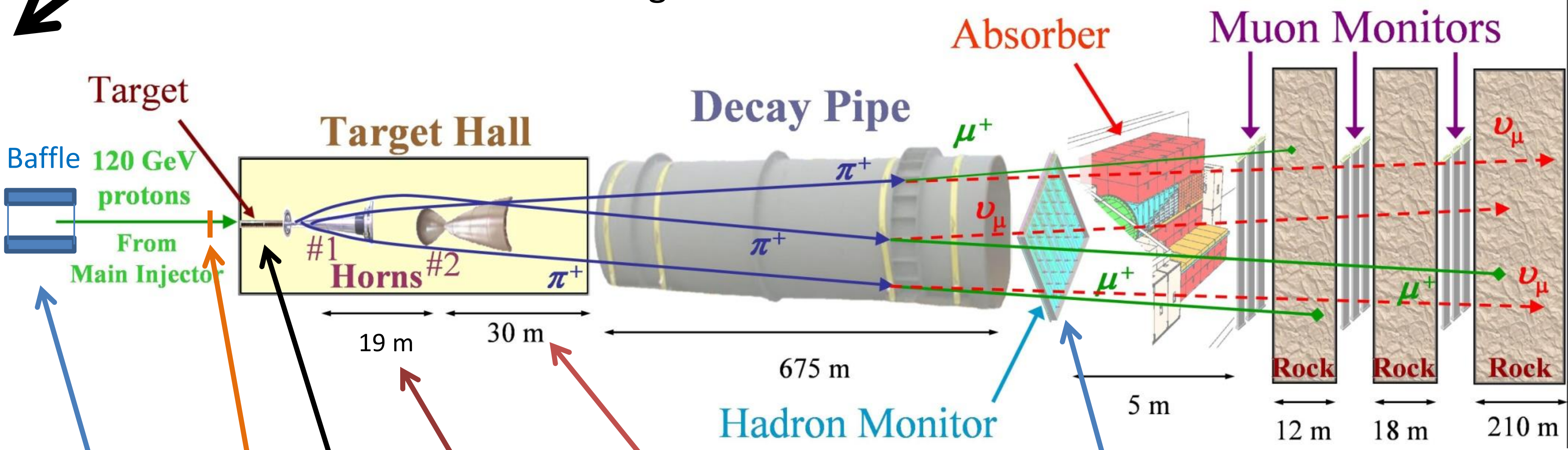
- longitudinal location

Near detector longitudinal & transverse locations

Far detector longitudinal & transverse locations

*Obviously not going to get through all those today, so **highlights***

Primary beam line: new quad magnets, new profile monitors,
Beam Position Monitor nearest target dismounted and re-installed



New hadron monitor

Horn 2 moved 9 m downstream

Horn 1 new for 700 kw operation

New style target for NOVA ME beam, no longer symmetric

New instrument (TVPT) for monitoring beam vertical position

New baffle (larger hole)

Substantial modifications to Target hall dehumidification system & RAW skids

Changes from MINOS to NOVA configuration

Timeline of beam adjustments

- Sept 4, 2013 11:27 — 1st beam after scans, turn on horns
- Sept 5, 2013 17:30 — adjust horn current up by 0.6 %
- Sept 9, 2013 11:00 — adjust spot size 1.7 mm -> 1.1 mm RMS (0.9 mm at low int.)
- Sept 10,2013 16:20 — adjust target position up by ~ 0.9 mm
- *Still to do* — *adjust spot size on target -> 1.3 mm RMS (needed at higher power)*
- *Done over months* — *timing of Lumberjack –datalogging of some quantities being modified for 1.33 second cycle time*

Horn current – note calibration change

Pulse shape slightly different (horn 2 move), and adjust to new extraction time (1.5 ms)

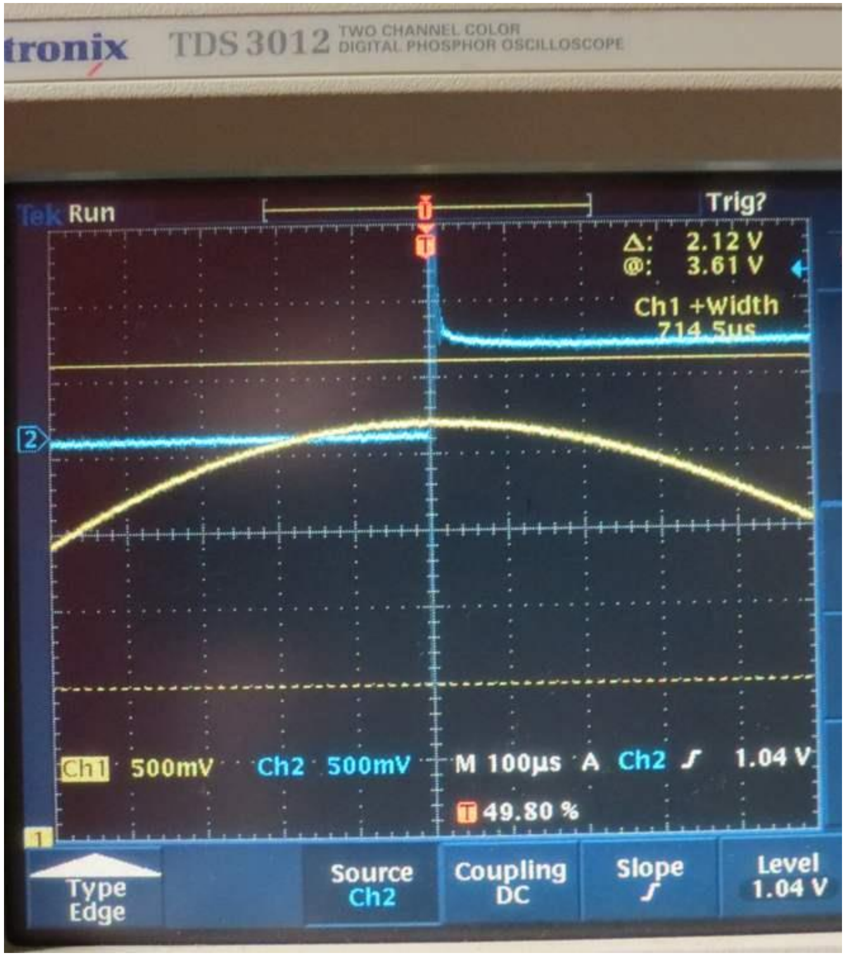
Beam to horn timing:

Blue: beam from target Budal

Yellow: horn current

100 micro-sec per division

Within ~ 20 microseconds, beam at horn peak



Calibration:

Correction for sample time from peak: 0.04%

All calibration applied for FY2014 run:

readout (E:NSLINA+B+C+D) is

99.54% of actual current

(previously 98.17% , MINOS-doc 1303)

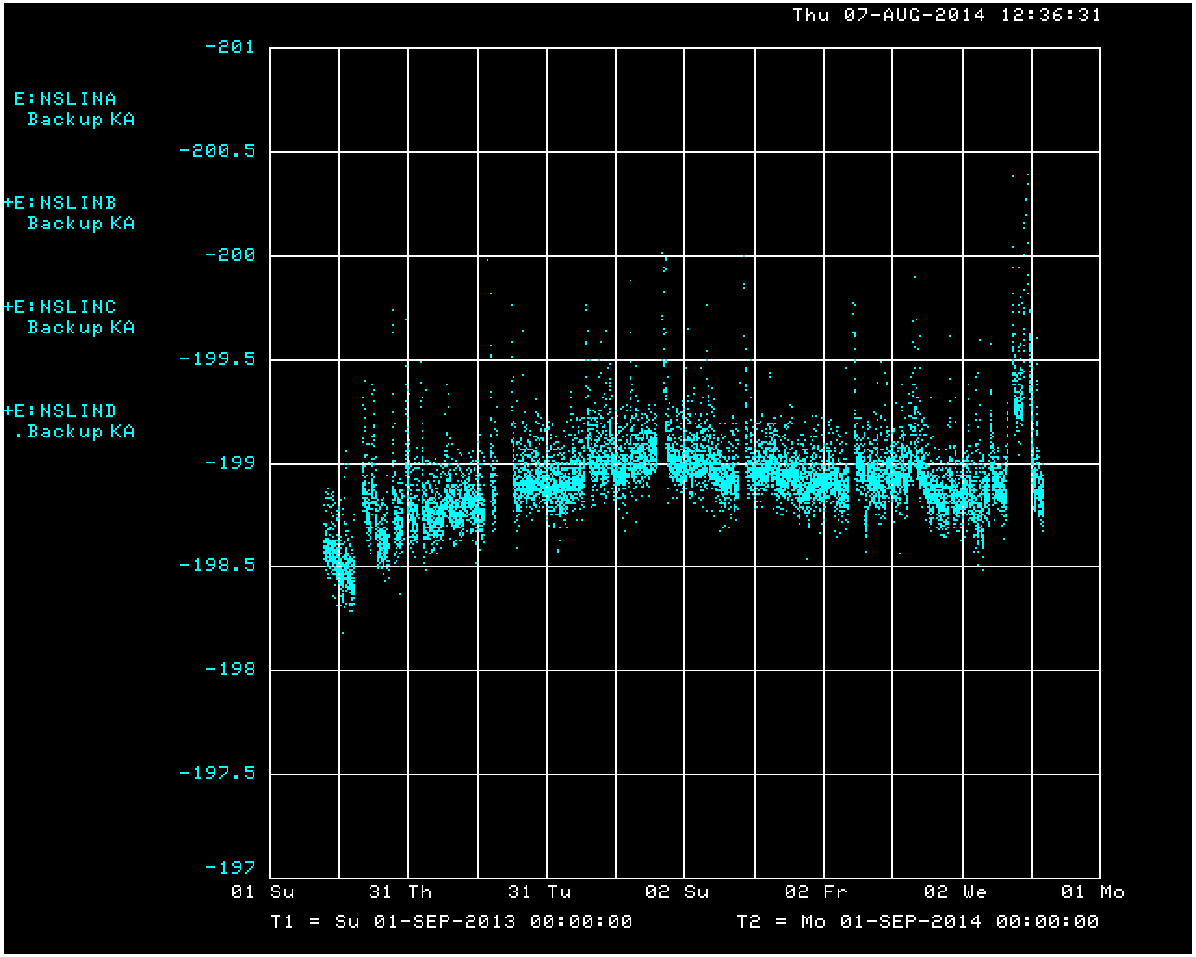
Operating Point:

Have set voltage to get 199 kA on readout

so 200 kA actual horn current (higher than previous “200 kA” runs)

Current is temperature (pulse rate) dependent, pulse rate increased since voltage first set, current looks 0.2% low end of Sep. 2013.

Horn current during FY2014



Remember 99.5% calib.
For 200 kA,
goal is 199 kA on plot

As stripline heats up,
horn current goes down

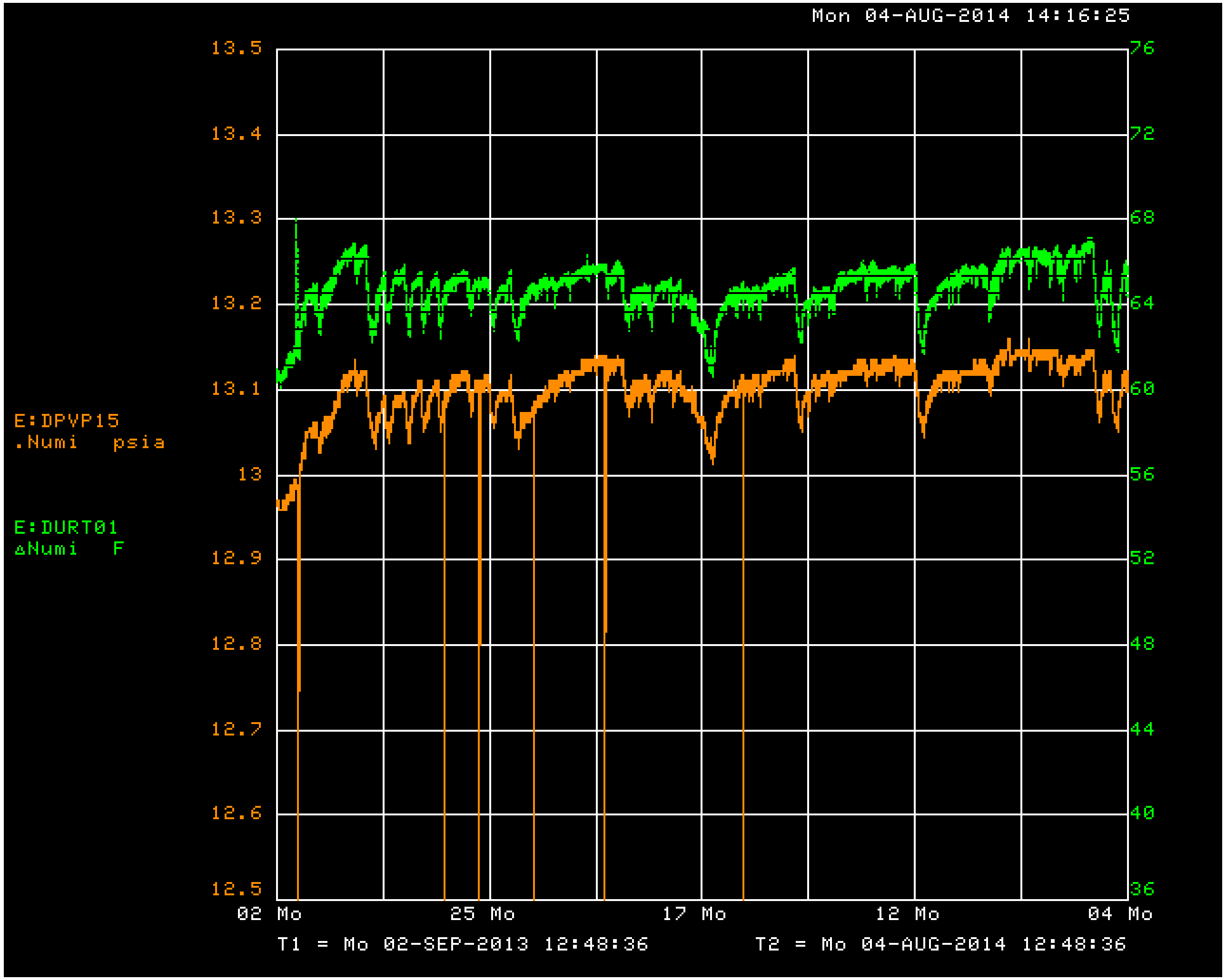
~ ½% more current when horn first turned on or when in power-conserving time-line

(end of May, ramp cards swapped, slow start card replaced)

On July 11, 2014 changed horn voltage set point from 721 V to 722 V
to compensate for shift from 1.67 sec to 1.33 sec running stripline heating

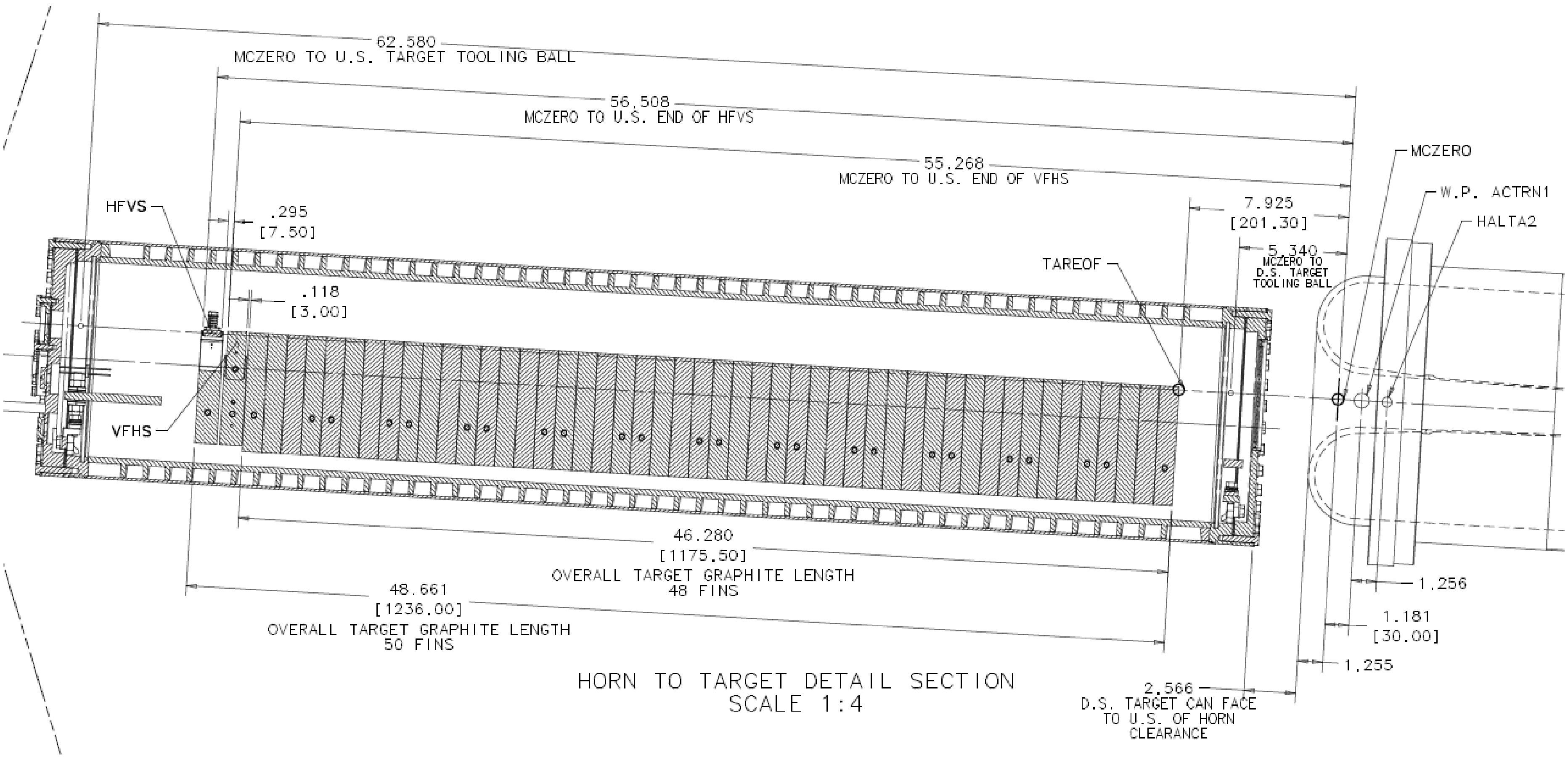
Suggest experiments do a POT weighted average

Decay pipe helium for FY14
~ 13.1 PSIA at 65 deg F
pressure tracks temperature, so same number of molecules



MET-01 (FY2014 NOVA-ANU) target longitudinal location

Integration planning drawing, not as-built, see next slide for as-installed dimensions



HORN TO TARGET DETAIL SECTION
SCALE 1:4

MET-01 (FY2014) target longitudinal location, & Horn 2

According to survey, Horn PH1-04 is installed 2 mm upstream of nominal, but as input to Monte Carlo, leave it at nominal (MCZERO) and adjust target instead.

Repeating, in previous LE target alignment report, MINOS-doc-9314, I listed target locations relative to horn 1 (not the absolute locations); to be consistent I will do that here as well.

Horn 1 starts at MCZERO (that is not the curved end-cap, but the start of nominal 3 m long "idealized" horn), as defined in the NUMI Technical Design Handbook.
(For reference to other drawings, the point ACTRN1 is 3 cm downstream of MCZERO).

For the 49 vertical fins (VFHS fin plus 48 normal fins).
Vertical fins start 1397.2 mm upstream of Horn 1/MCZERO
Vertical fins end at 194.3 mm upstream of Horn 1/MCZERO

The cross fin (HFVS fin) starts 31.5 mm upstream of the vertical fins,
and ends 7.5 mm upstream of the vertical fins

The gap between the first vertical fin (VFHS) and the rest of the vertical fins is 3.0 mm, while nominal gap between rest of fins is 0.5 mm

Start of horn 1 (MCZERO) to start of horn 2 (ACTRN2) is 19180.0 mm.

I estimate the systematic errors to be around 2 mm, having to do mostly with weld shrinkage in the horns and optical sighting down to tooling balls in target hall.

Argon, Water in Horn

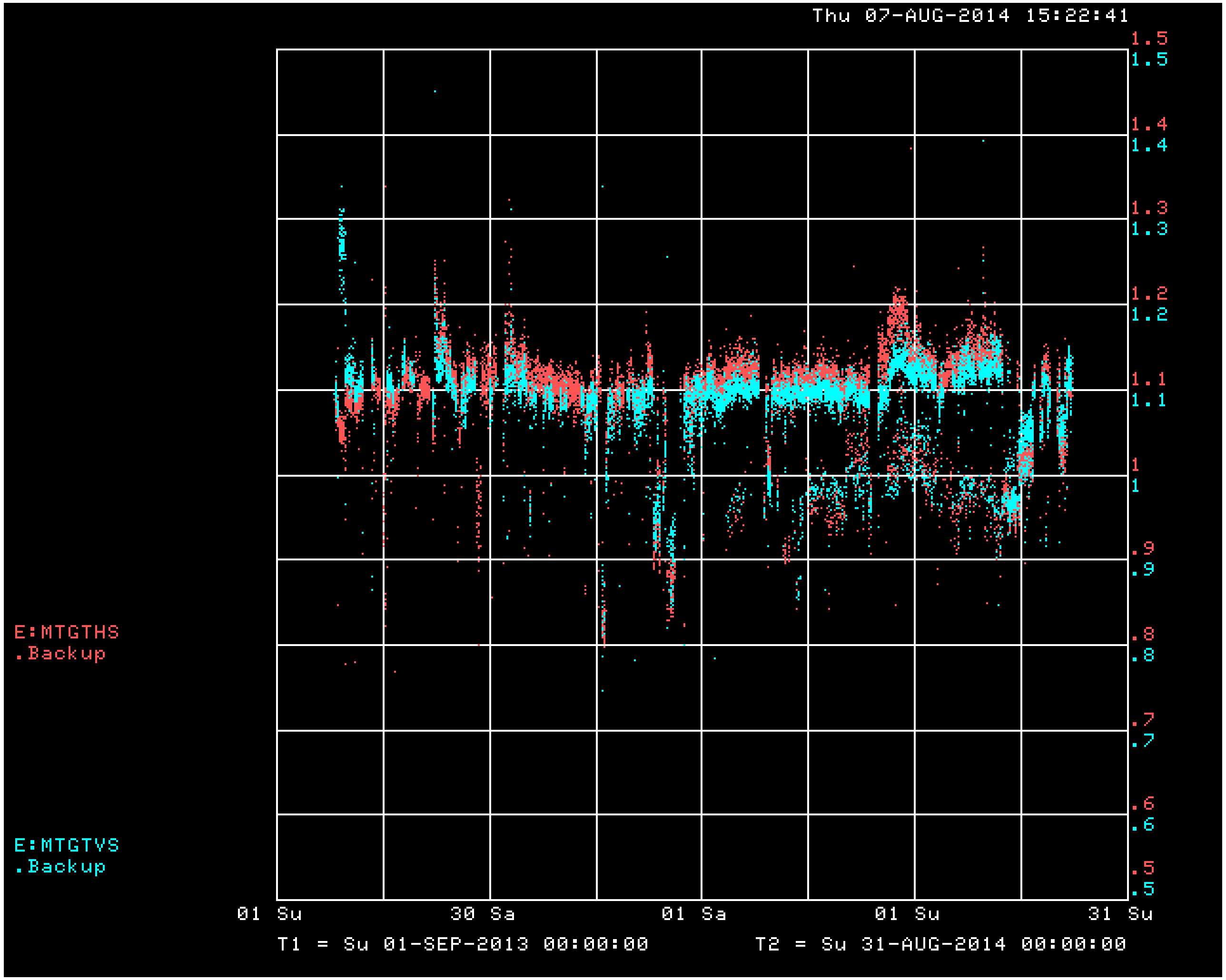
Horn is filled with Argon gas at atmospheric pressure to give inert atmosphere
likely to be at 100% relative humidity, with some H_2, O_2 from water dissociation

Horn is water spray cooled. Two components of water in horn 1:

1. Film on inner conductor,
   ~ 1 mm at neck, somewhat smaller on rest of conductor,
   amplified by going through this layer at small angle

2. Spray – droplets in space
   estimate pion could traverse on average anywhere from 0.02 mm to 7 mm H_2O
   depending on path (near neck or 10 cm radius through entire horn) and
   assumed spray velocity

Beam spot size FY2014
around 1.1 mm RMS



Horz. & Vert. RMS
at profile monitor TGT
8 m upstream of target

Spot varies w. emittance, correlated to POT/spill

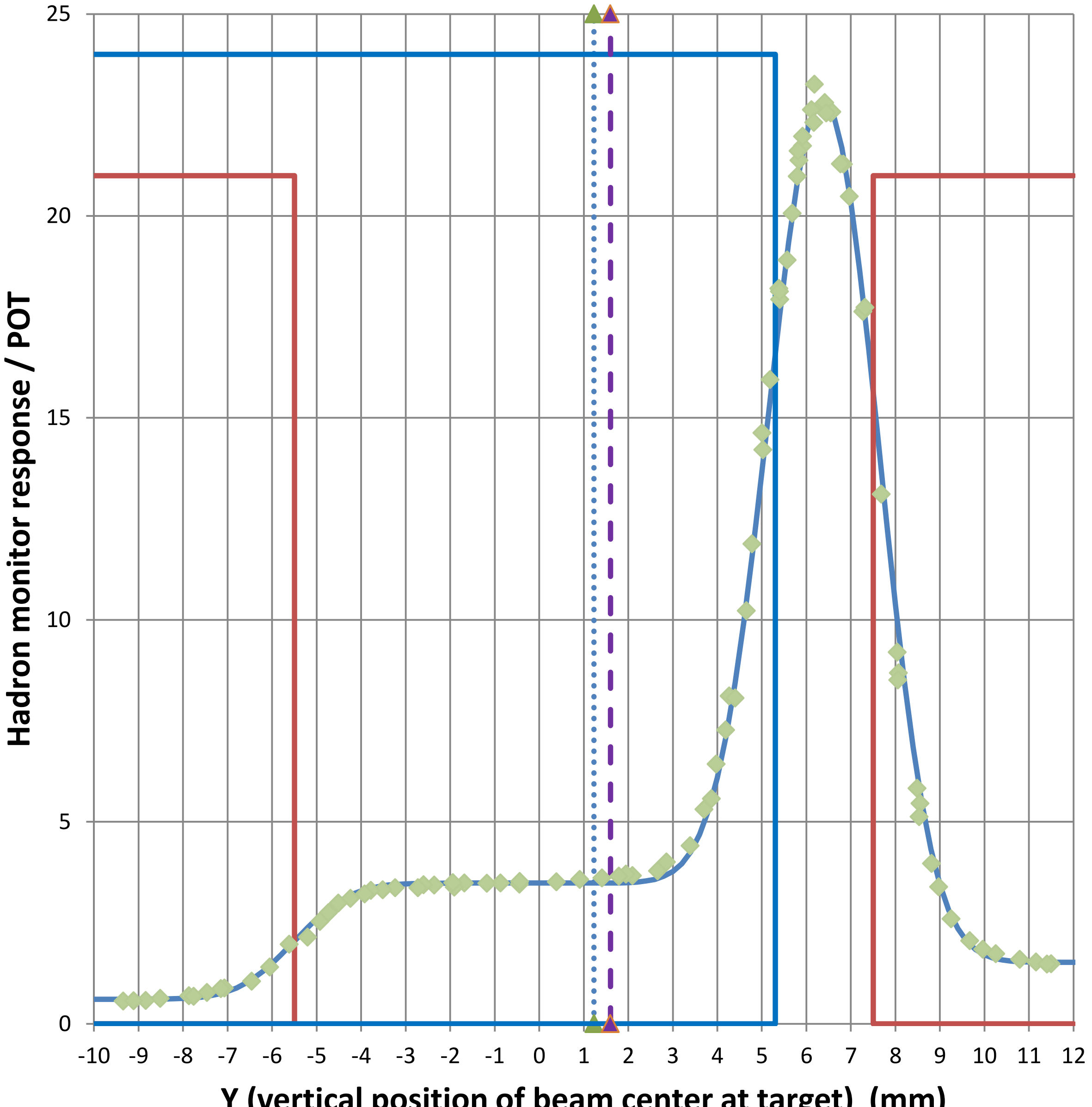
Most of variation to date from recycler beam having lower POT/spill

Size is under study, since will have to increase for slip stack beam

RMS at target may be ~0.1 mm smaller than at PMTGT

Fits of same PM data differ by ~ 0.1 mm

Vertical beam to target alignment

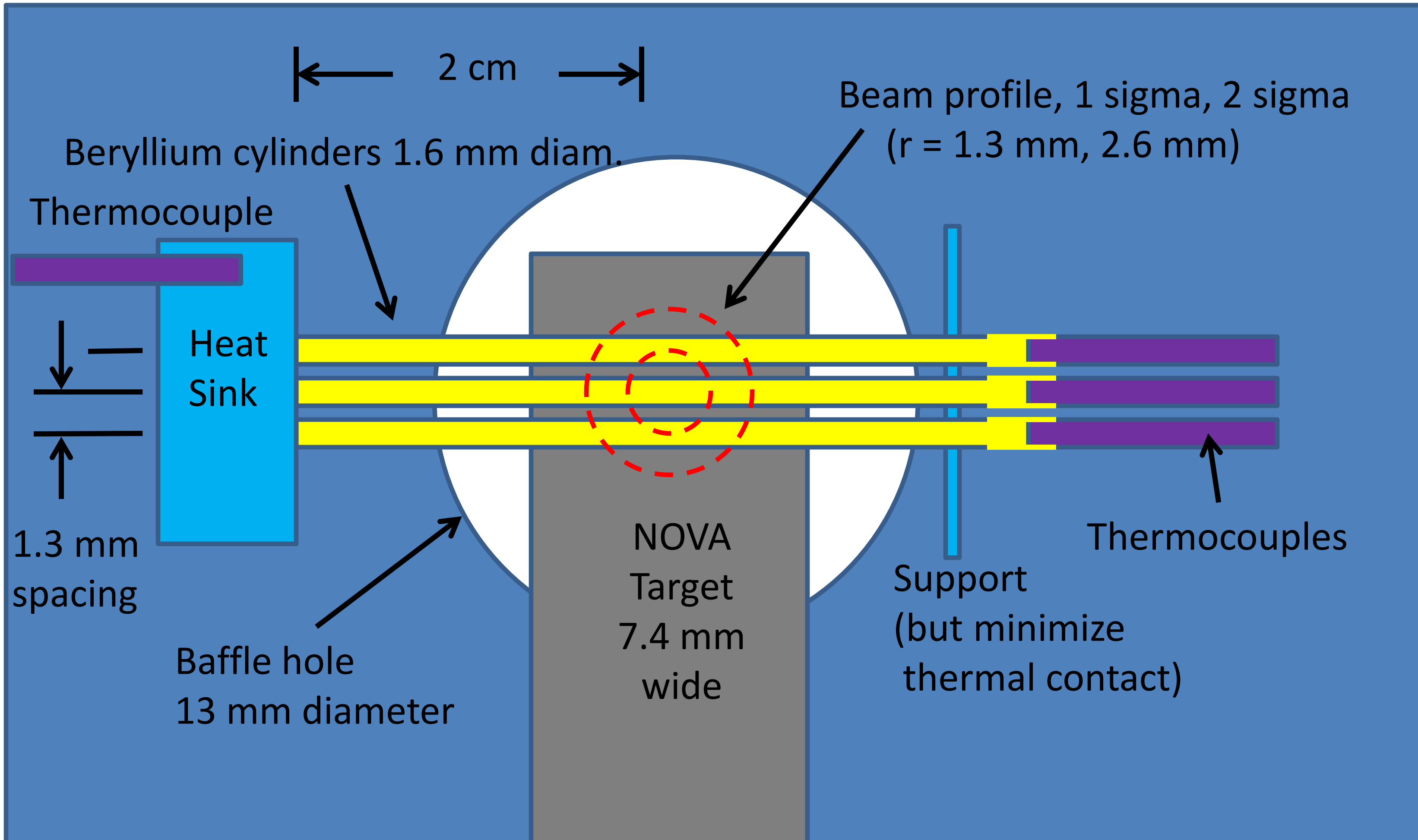


Scan at low intensity using hadron mon. indicates we are aiming beam ~ 0.4 mm too low on target

Scan May 29, 2014

Concept of Target Vertical Position Thermometer

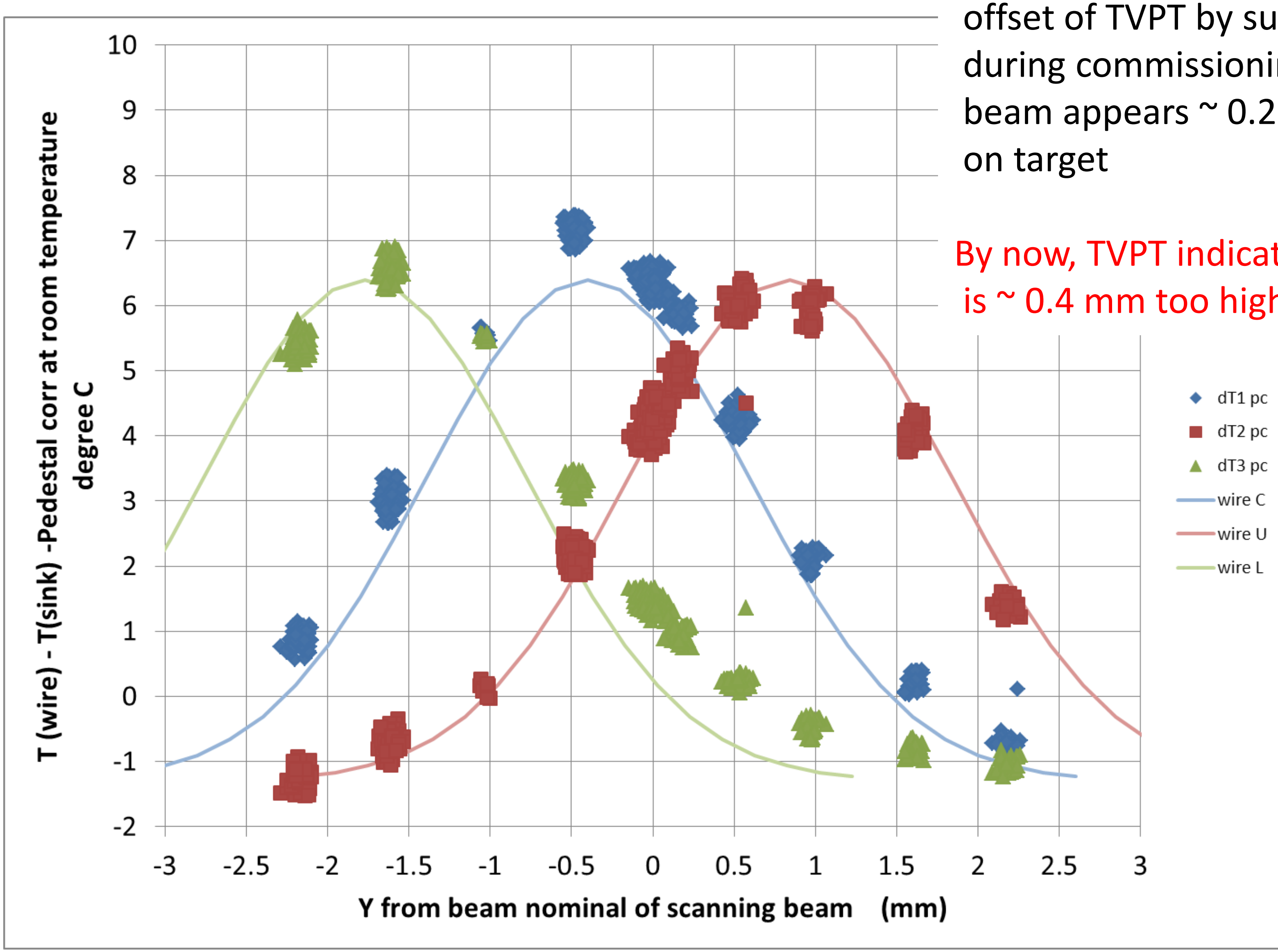
(not to scale; note baffle drawn behind target, although it is actually in front)



Scan of TVPT at high intensity

After for correcting for 0.2 mm offset of TVPT by survey, during commissioning beam appears ~ 0.2 mm high on target

By now, TVPT indicating beam is ~ 0.4 mm too high on target



Vertical alignment complications

During commissioning, had a bad front end electronics card,
Beam Position Monitor readout was drifting, giving inconsistent scans

Later, find that Beam Position Monitor readout is intensity dependent
Have replaced worst non-linear card
Have proposal to attenuate signal, not clear what that would do to low intensity scans

Would like to do another TVPT calibration scan when have some free time
and also push analysis further

Right now, have +/- 0.4 mm error on vertical beam position on target
because one monitor says we are high and the other says we are low

Summary of scan results

HORZ.	X seen			Beam Set to:	Beam Set to:	X from beam (mm)
	0.82		H1 neck	1.00	1.00	-0.18
	0.63		H1 fin	1.00	1.00	-0.37
	1.80		H2 fin	1.00	1.00	0.80
ave	1.08					
			target	1.00	1.00	0.0
			Had mon			-18
VERT.	Y seen			E:VP121	E:VPTGT	Y from beam (mm)
	0.47		neck	0.00	1.00	0.47
			H1 fin			
	-1.10		H2 fin	0.00	1.00	-1.10
ave n,n,h2	-0.05					
			target	0.00	1.00	-0.5 to + 0.5
			Had mon	0.00	1.00	-15

From NuMI TDR - *tolerances*

	PH2me	Medium	Energy	Beam
	A	B	C	D
	estimated accuracy	Will cause 2% error	error in worst energy bin	error squared
At Fermilab	(mm)	(mm)	(%)	(%)
Position of Beam on Target	0.38	1.20	0.201	0.040
Angle of Beam on Target [18.13m]	0.71	8.16	0.015	0.000
Target X	0.50	-	0.000	0.000
Target Angle [1.0m]	0.71	1.67	0.362	0.131
Horn 1 X &	0.50	0.89	0.645	0.416
Horn 1 Angle [3.0m]	0.71	1.69	0.353	0.125
Horn 2 X	1.00	4.28	0.109	0.012
Horn 2 Angle [3.0m]	0.71	23.00	0.002	0.000
Decay Pipe [675m] Downstream End	25.00	270.00	0.017	0.000
Near Detector	25.00	209.00	0.029	0.001
Sum			*0.851*	0.724
Times root 2, since two transverse planes			*1.204*	1.449

Protons

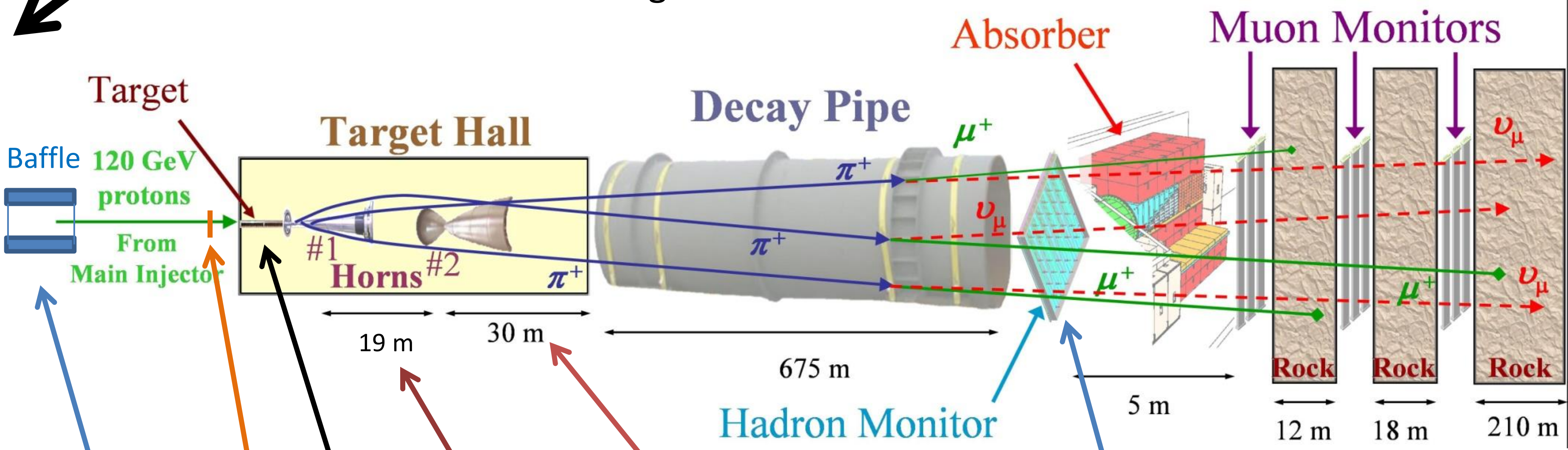
- 2005-2012MI Booster into Main Injector, using slip stacking to fit 11 booster batches into 6 M.I. batch slots, 2.1 to 2.4 second cycle time
- FY2014 start with un-slip-stacked beam 6 booster batches to M.I. at 1.67 seconds cycle time
- Moving to un-slip-stacked 6 booster batches stacked in recycler then injected to M.I. at 1.33 second cycle time
- Over the next year, move to slip-stacking in recycler, providing higher power
- By ~ year from now, finish replacing booster RF cavities, providing enough booster batches to reach 700 kW

- Old slip-stacked beam up to 4e13 POT/spill
- Current un-slip-stacked beam ~ 2.4e13 POT / spill
- Goal recycler slip-stacked beam 4.9e13 POT/spill

Backup

- Mostly from 9/27/2013 talk given describing NUMI startup

Primary beam line: new quad magnets, new profile monitors,
Beam Position Monitor nearest target dismounted and re-installed



New hadron monitor

Horn 2 moved 9 m downstream

Horn 1 new for 700 kw operation

New style target for NOVA ME beam, no longer symmetric

New instrument (TVPT) for monitoring beam vertical position

New baffle (larger hole)

Substantial modifications to Target hall dehumidification system & RAW skids

Alignment Step 1: center beam into hadron monitor (without target in way)

last vertical BPM appears 1.00 to 1.25 mm low; go with hadron monitor angle.

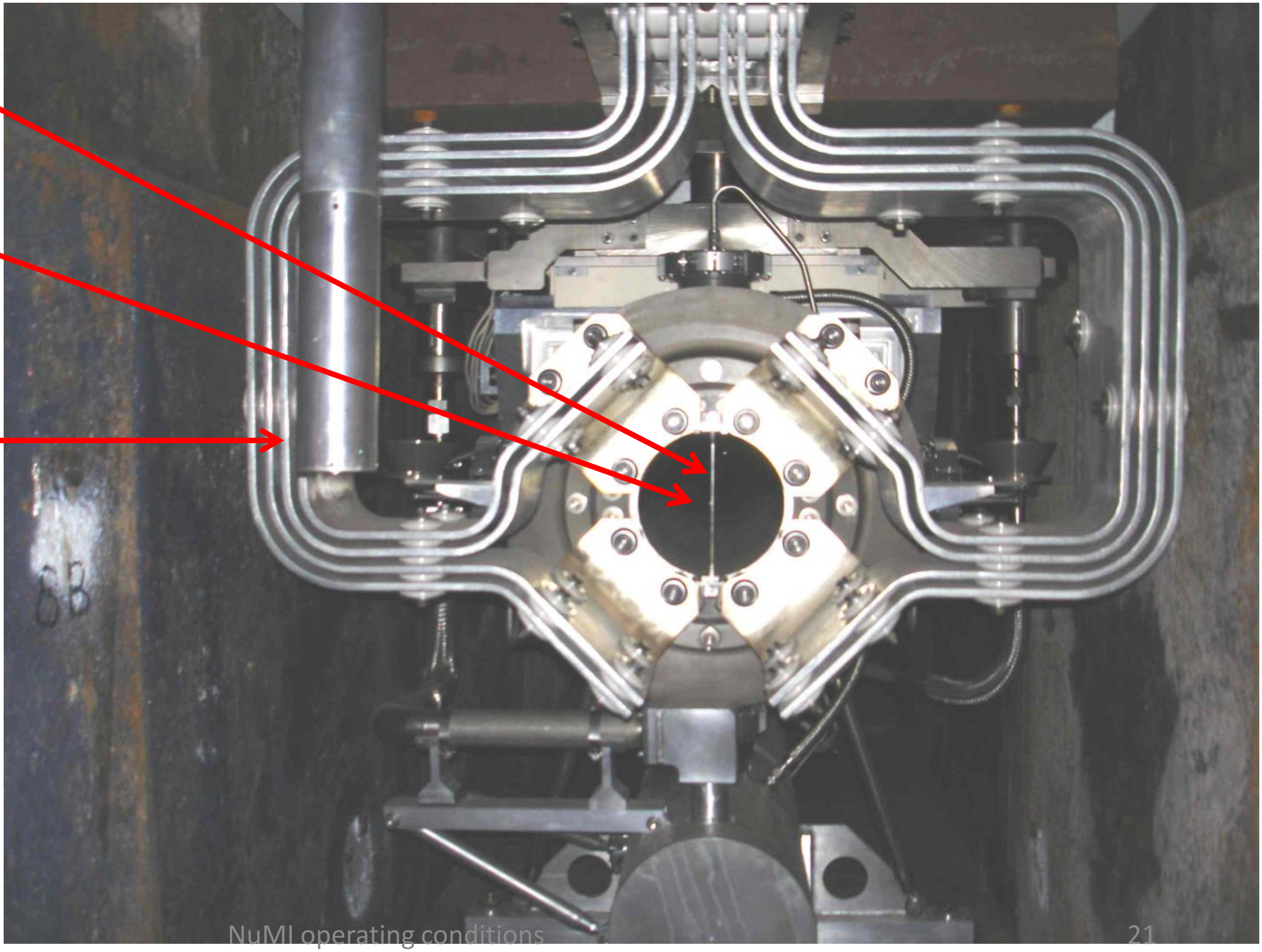
Correct Y from final BPM by 1.00 mm in most of following slides.

Step 2: scan beam across horn "cross hairs" and horn 1 neck

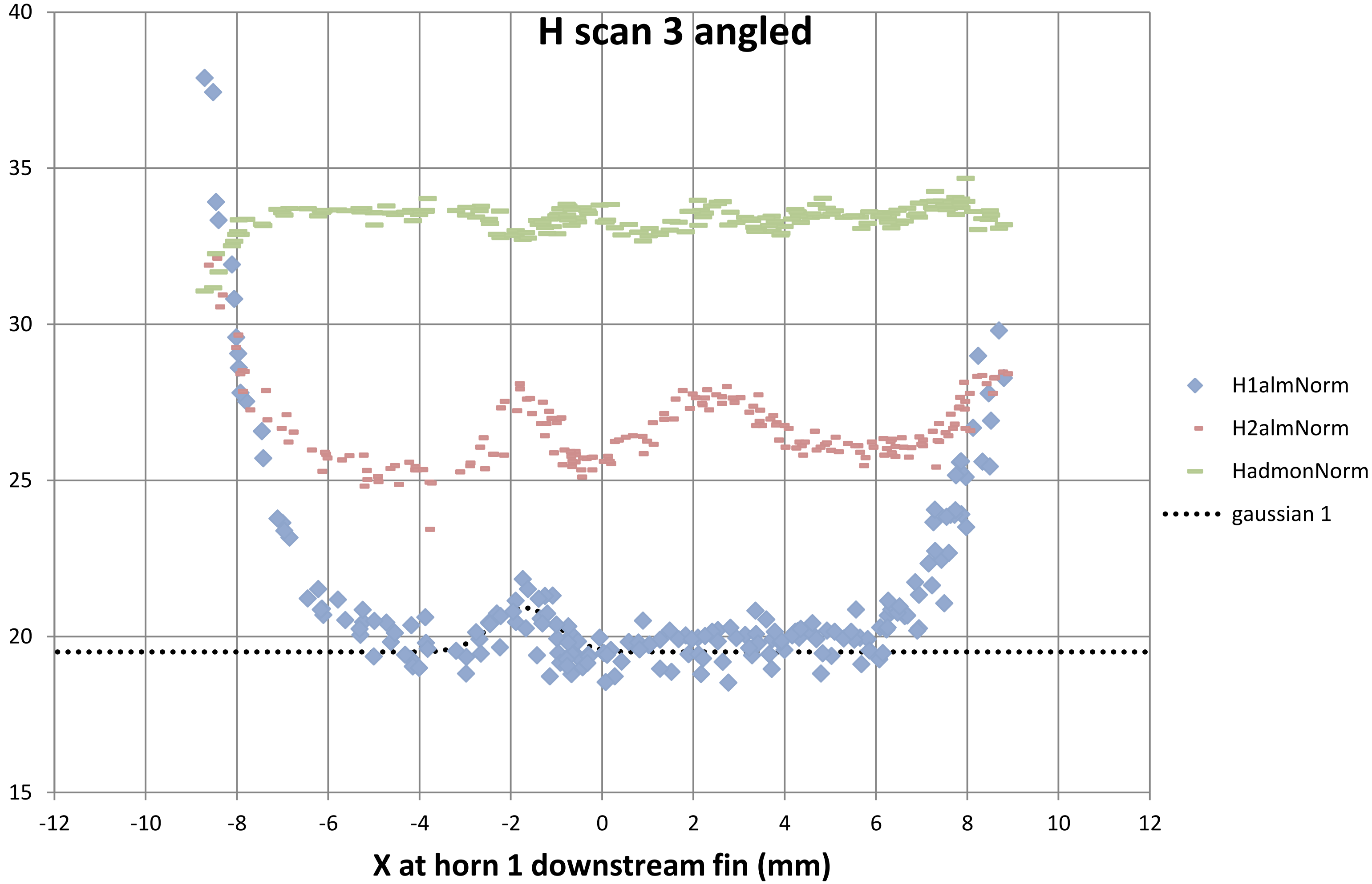
Fin for beam
horz. alignment

Nub for beam
vert. align

Beam loss mon.
to detect beam
scatter from fin



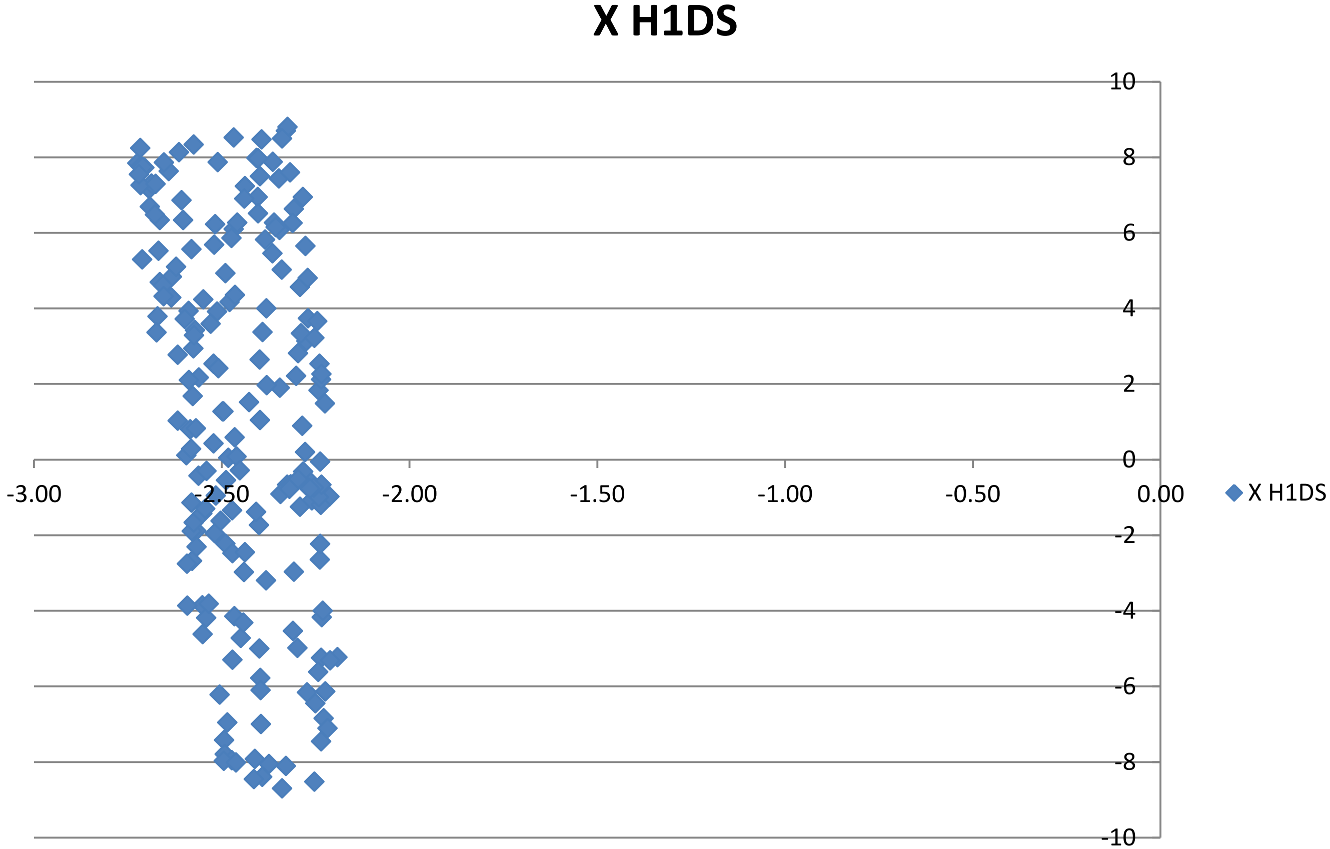
See horn 1 fin in BLM 1
Also see sculpting from horn 1 neck



Scans done at low intensity to not destroy horns etc

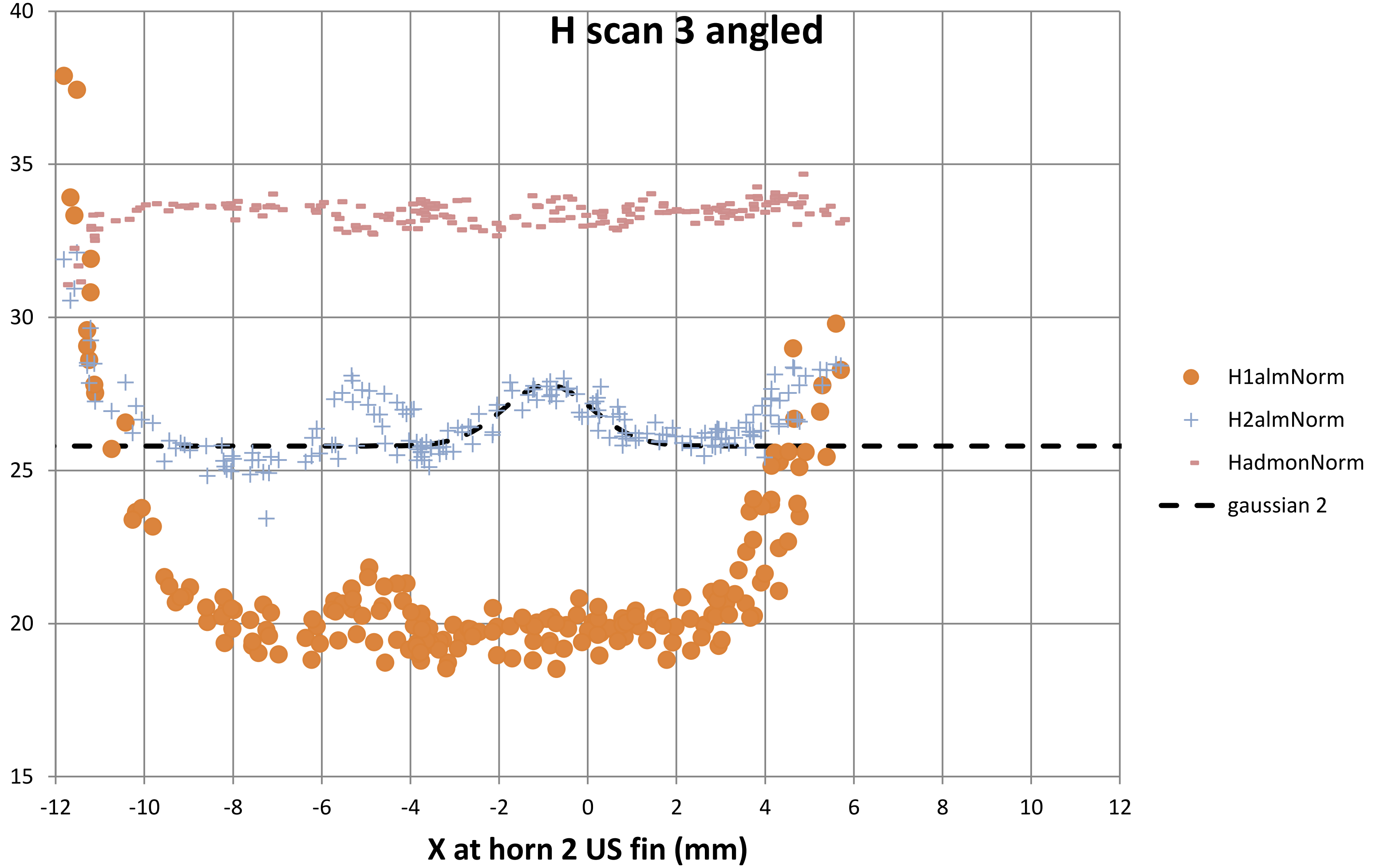
At low intensity, get ¼ mm jitter in relative BPM readout

(H scan 3 angled scan)

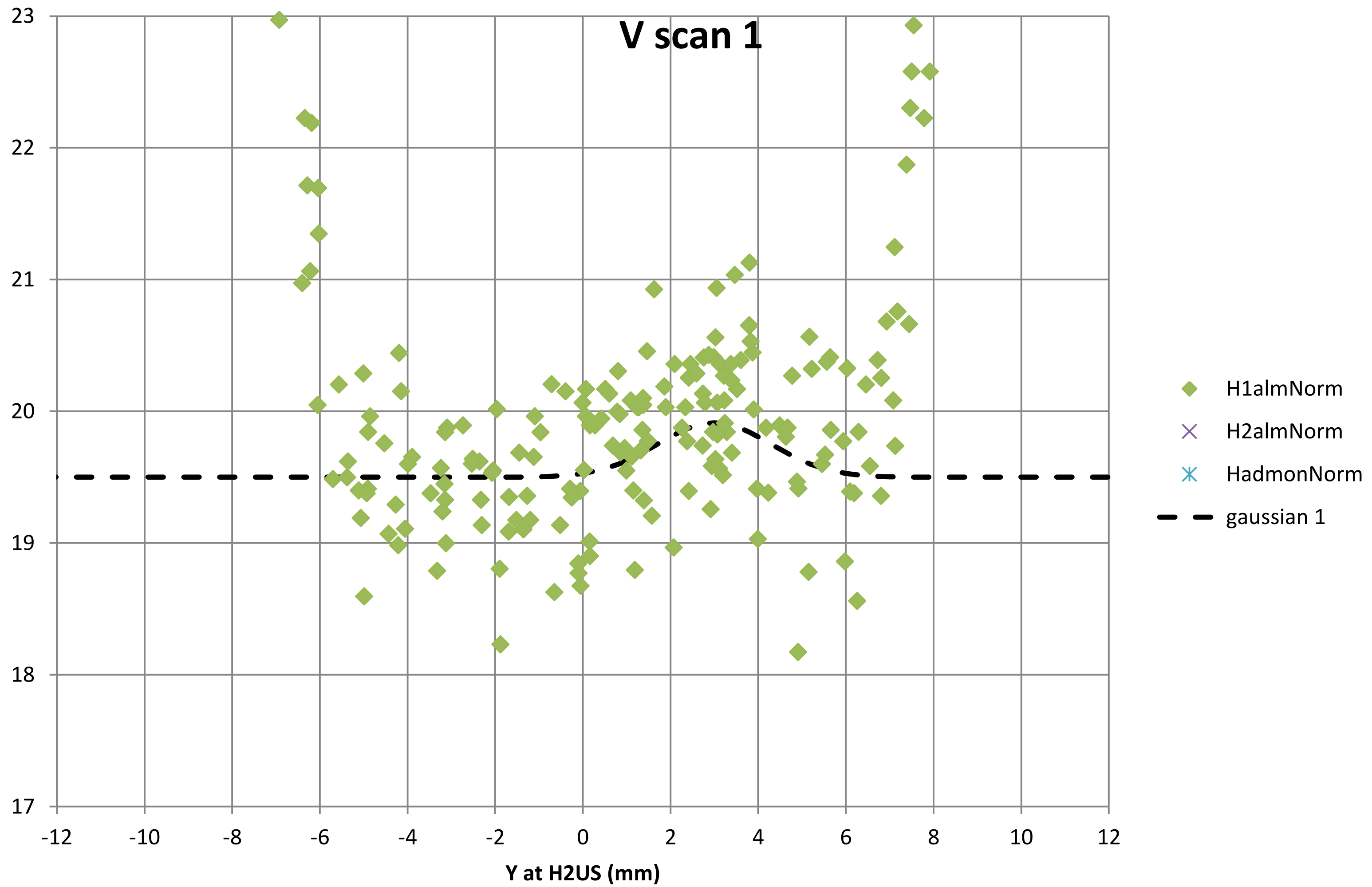


(Slope) BPMs HPTGT-HP121 (mm)

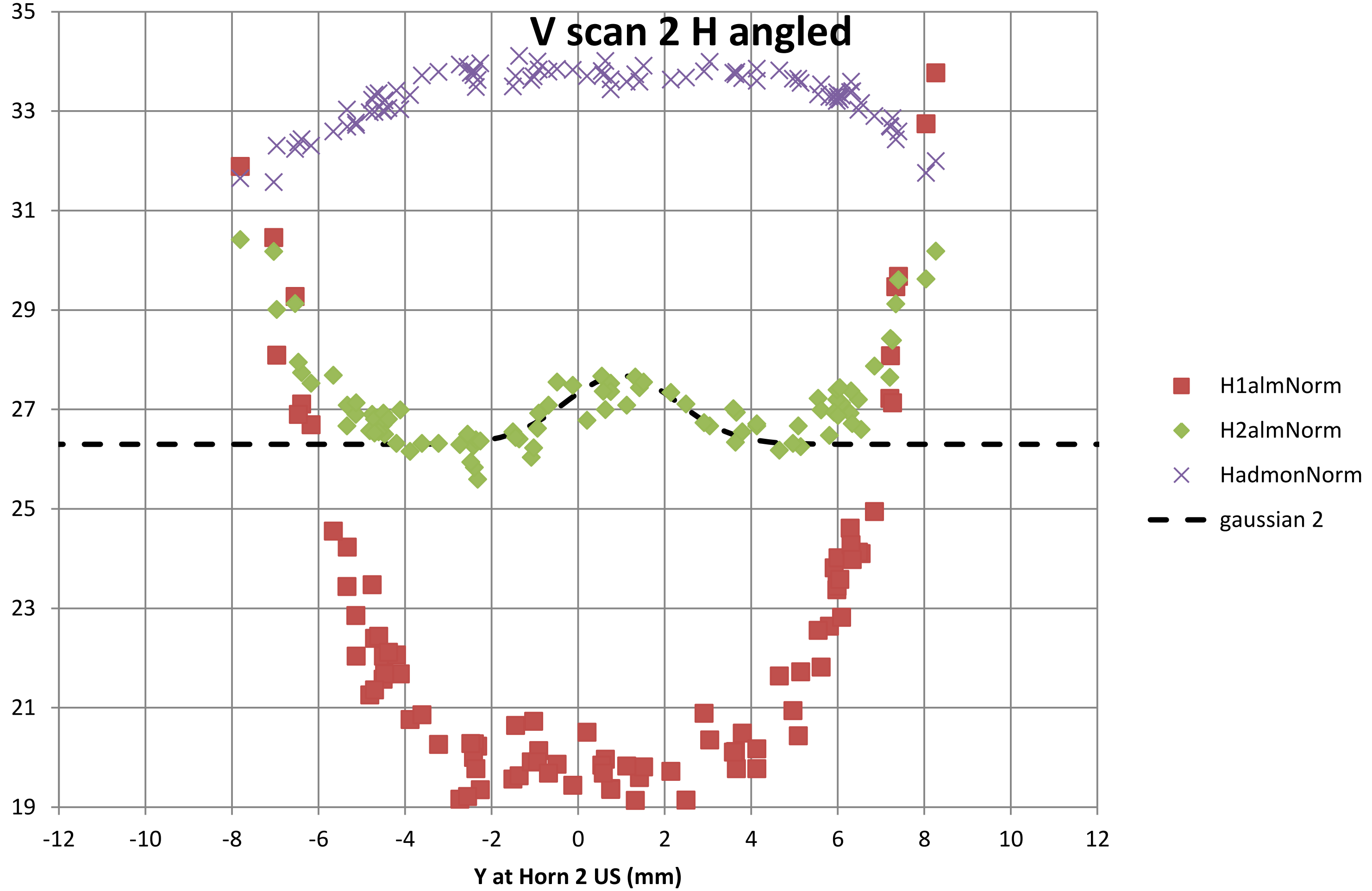
See horn 2 fin in BLM 2
(along with spray from horn 1 fin)



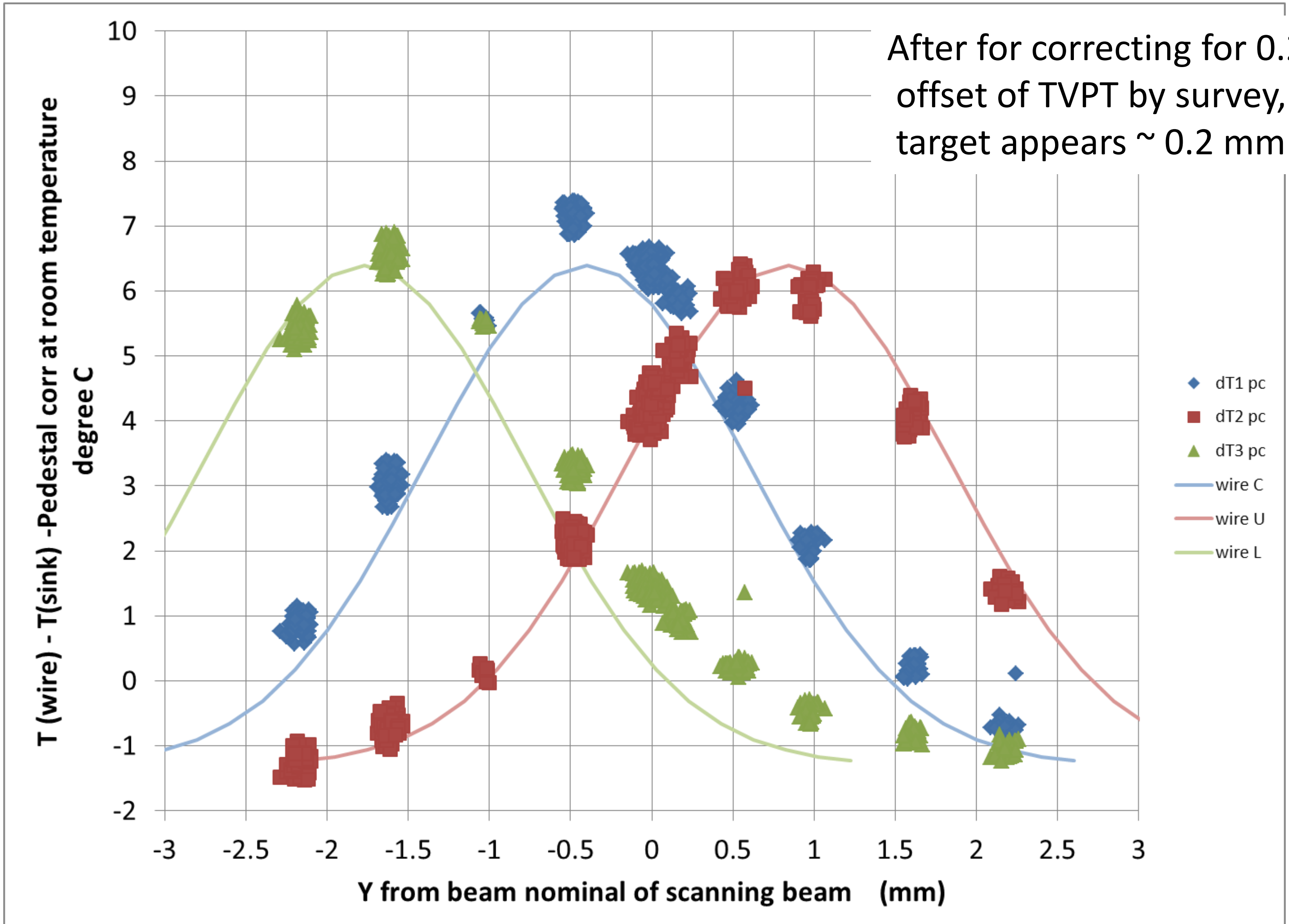
See feature Consistent with H1 fin nub, but set horn 1 vertical from much more obvious horn 1 neck feature



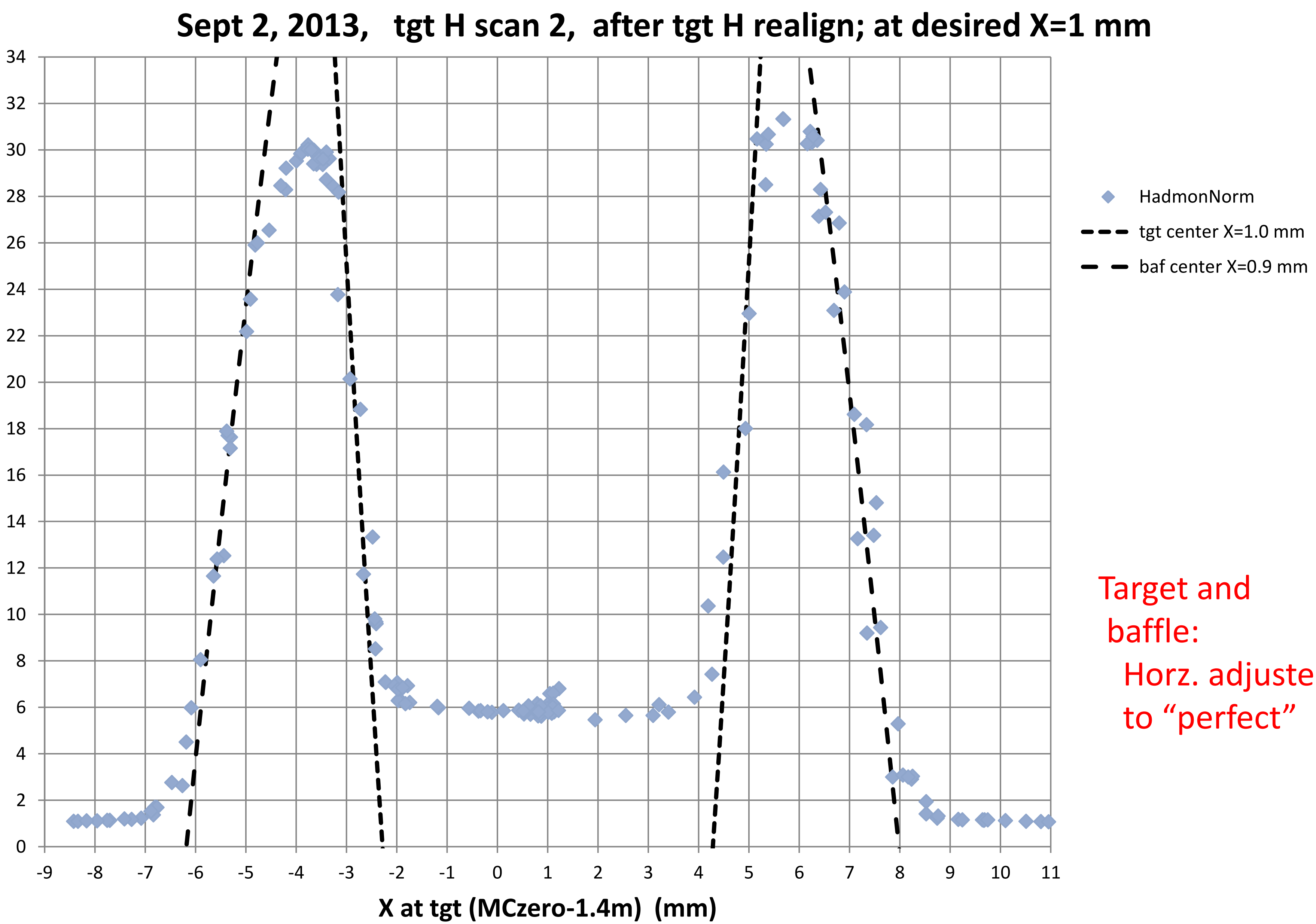
Horn 2 nub sets horn 2 vertical



Scan of TVPT at high intensity

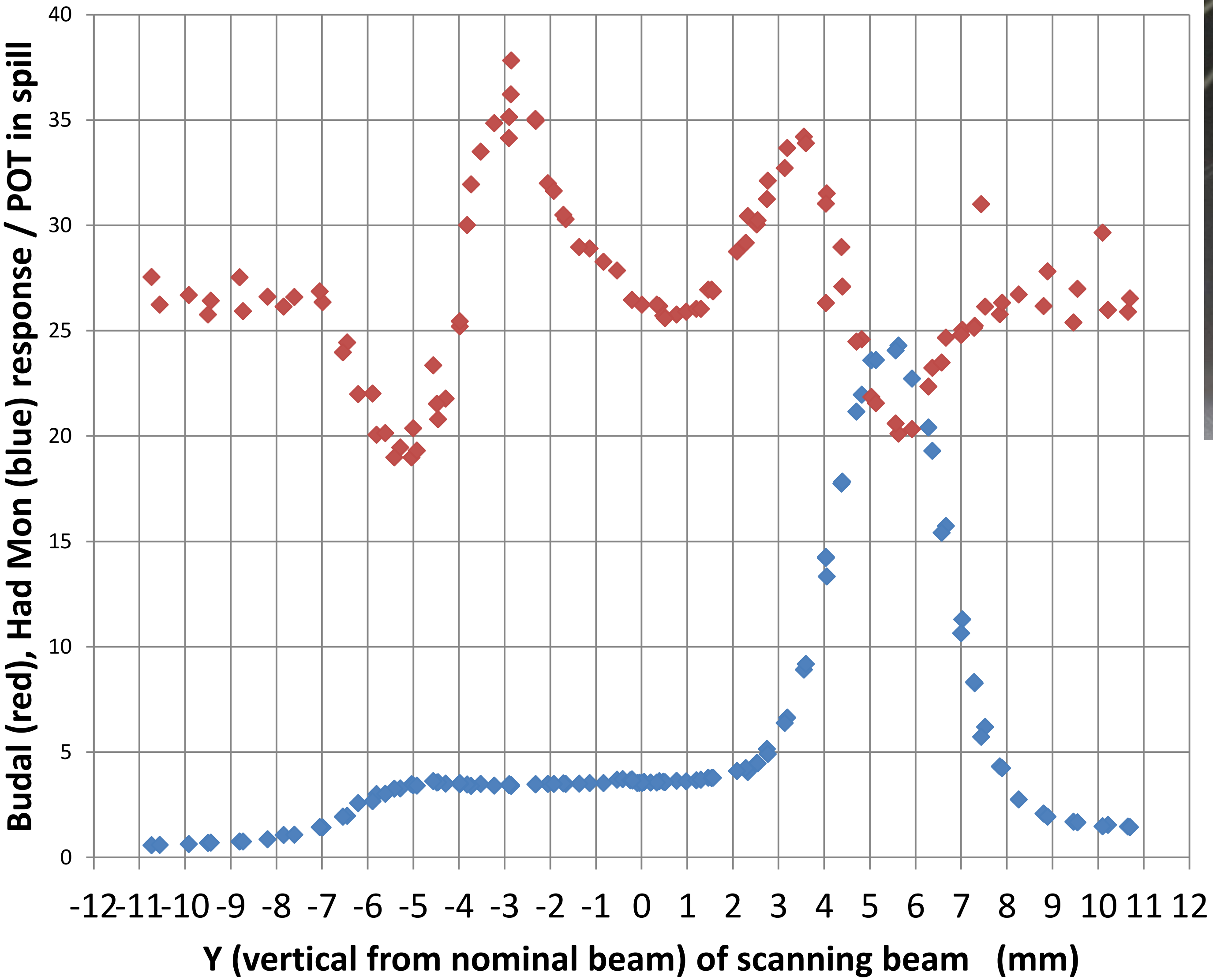


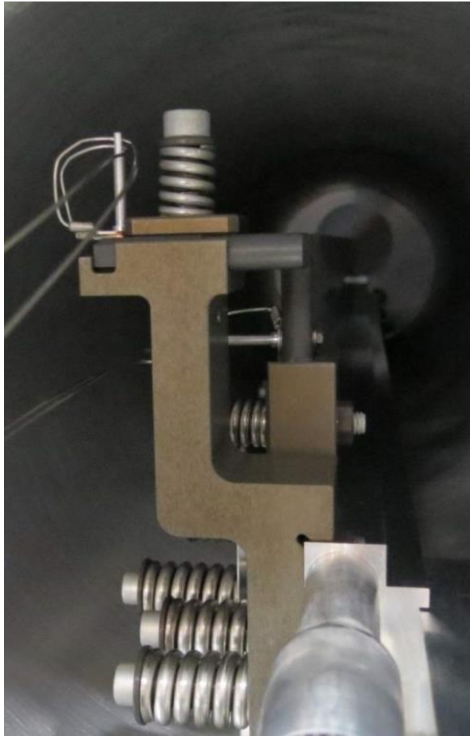
Step 3: install target and scan / realign target & baffle - - horizontal done with Had. Mon.



Target and baffle:
Horz. adjusted to “perfect”

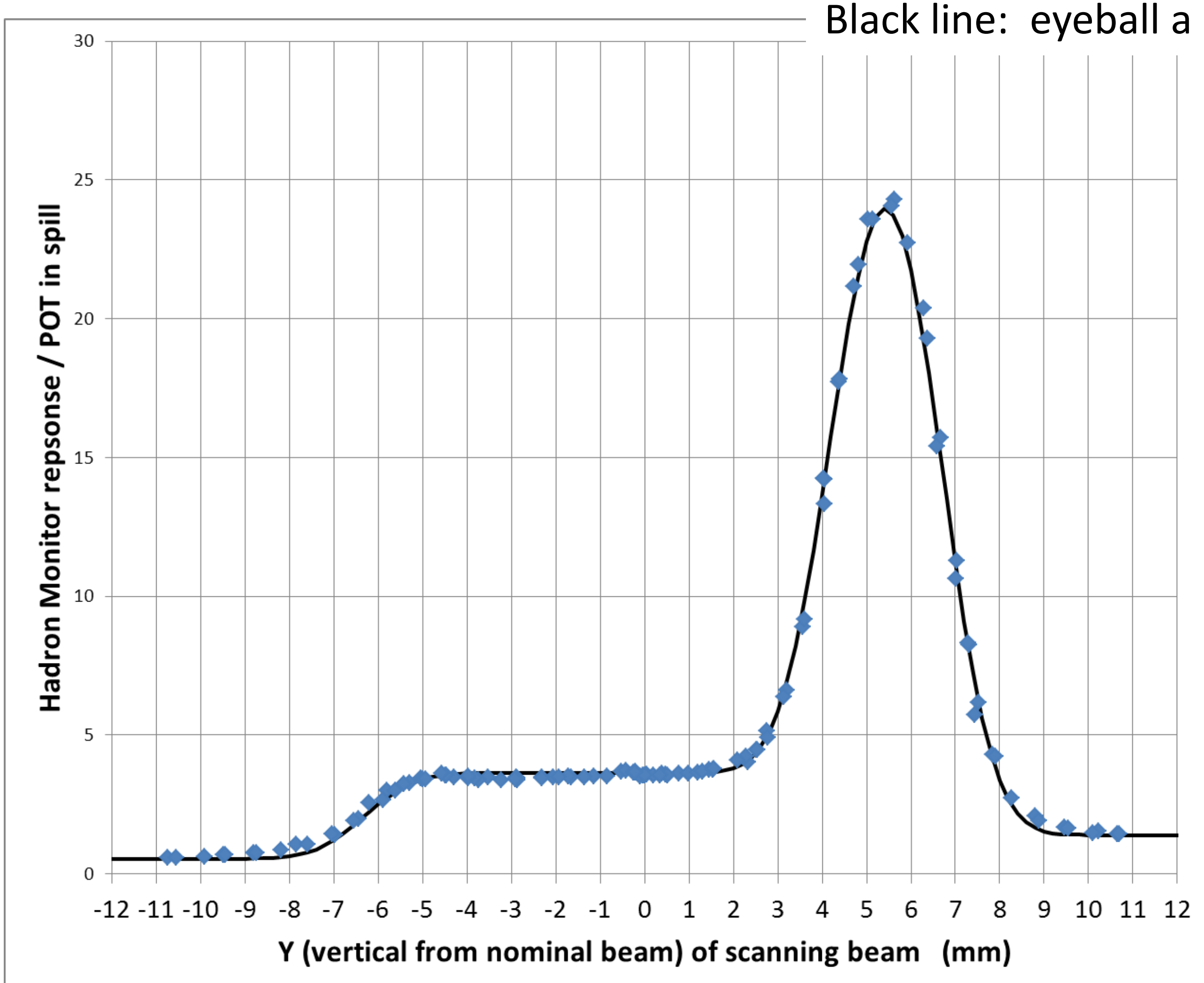
Target Vertical position
from Budal cross-fin scan at low intensity





Budal fin (and thus Target)appears high by ~ 0.3 mm

Target Vertical position
from Hadron Monitor scan at low intensity



Black line: eyeball a “fit” with parameters:

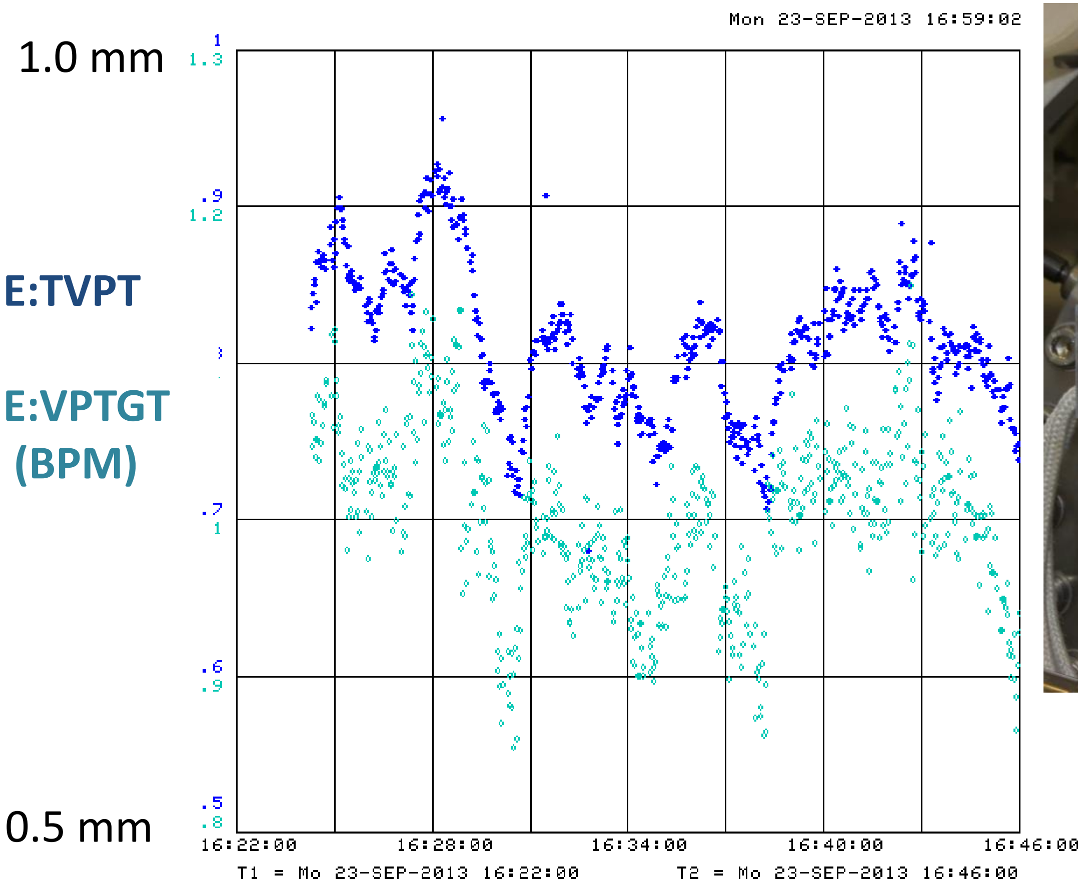
0.9 mm beam RMS
Y target edge
Y baffle edges
13mm apart
overall amplitude
3attenuation ampl.
upper baffle
target
lower baffle

Target appears high by ~ 0.5 mm

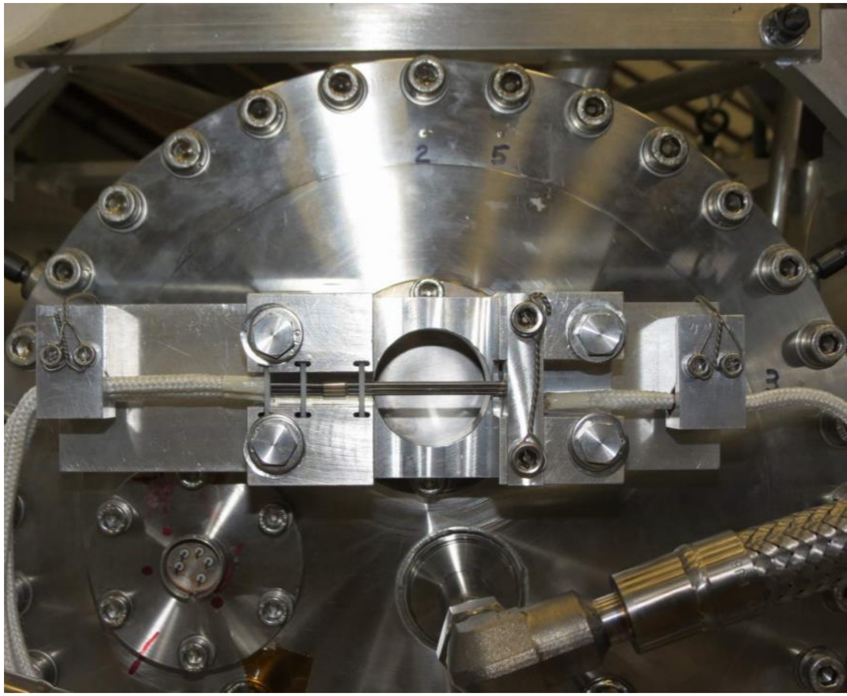
But don’t trust this so much

TVPT monitor during running

(does not require low intensity scan)



Time (24 minutes total)



Cobbled algorithm for TVPT
(dT top wire) / (dT central wire)
shows it can track beam motion
at 0.1 mm precision

Summary of scan results

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	0.47		neck	0.00	1.00	0.47
			H1 fin			
	-1.10		H2 fin	0.00	1.00	-1.10
ave n,n,h2	-0.05					
			target	0.00	1.00	**-0.2** to +0.5
			Had mon	0.00	1.00	-15

From NuMI TDR - *tolerances*

	PH2me	Medium	Energy	Beam
	A	B	C	D
	estimated accuracy	Will cause 2% error	error in worst energy bin	error squared
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Sum			*0.851*	0.724
Times root 2, since two transverse planes			*1.204*	1.449

Primary Beam changes

- As part of ANU upgrade
  - 5 quad magnets changed out (better cooling to allow faster repetition rate)
  - Optical Transition Monitor replaced by “low intensity” profile monitor
  - Prototype “button” BPM installed between 121 and TGT, new style for LBNE
  - Total Loss Monitor modified
  - Better readback of magnet currents for regulation, beam permit

- Due to failures
  - 20’ dipole magnet replaced
  - Trim magnet replaced
  - Beryllium window at end of pre-target beam pipe replaced

Proposal: Test of Beryllium target material ?

- Be is order of magnitude more radiation resistant than graphite
- Longer lifetime has advantages:
  - Slower deterioration, more stable neutrino flux to experiments
  - Save lots of money on construction, installation, storage, disposal of targets
  - Less downtime for replacement of targets
- Be targets have run for extended periods (WANF, Mini-BOONE)
- Replacement of NuMI graphite by Be pushes stress to yield limit
  - Believe Be will survive, but how to test?
  - Propose putting in a couple Be fins, one in highest stress region, one in lower stress region
  - Loss of one fin out of 50 should not make a target non-functional

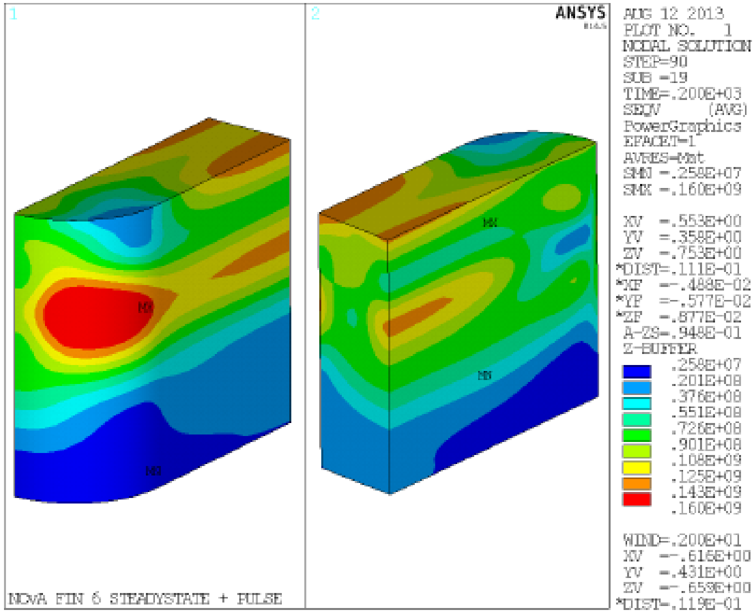
    So minimal impact in case of failure

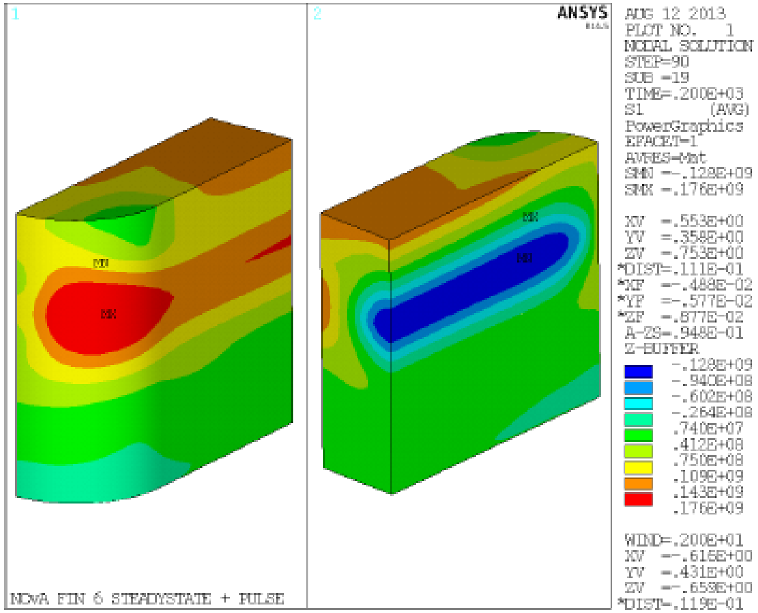
    Success might save 8 targets during NOVA run & help LBNE design
- NuMI prototype target test took pulses on Be calculated to be beyond yield point with no visible damage, but did not do sustained running – so want NOVA test

ANSYS of most stressed Be fin, by Brian Hartsell

Fin 6 Stresses - After First Pulse

Left figure is Von-Mises stress, right is maximum principal stress.

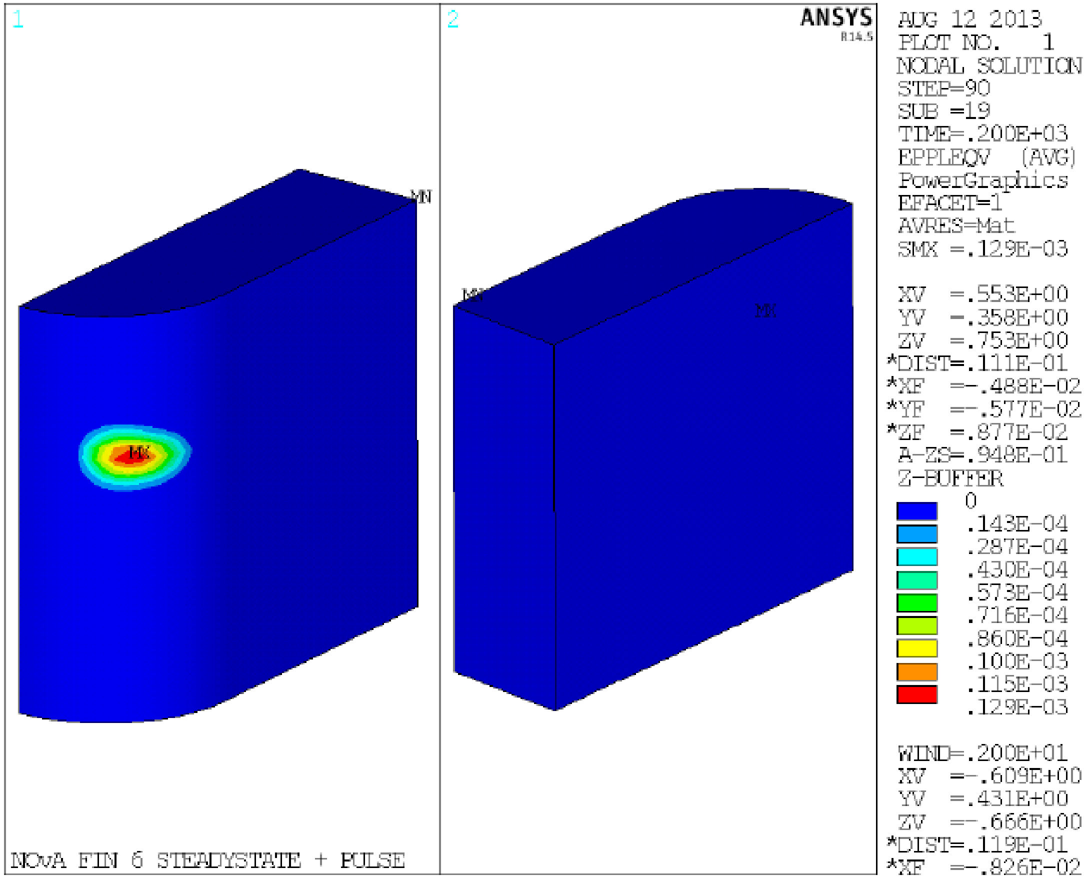




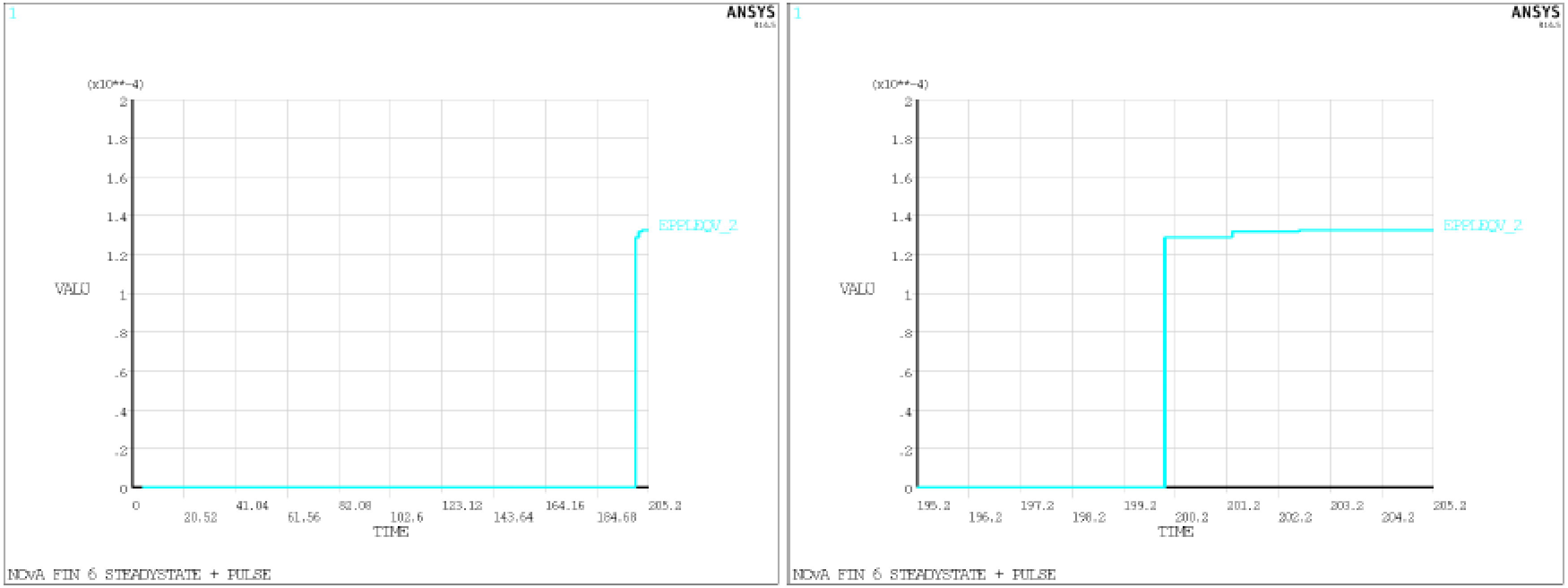
Fin is yielding at the large red spot - Yield is 160 MPa at this temperature.

Fin 6 Plastic Strain - After First Pulse

A small amount of yield is shown with 0.013% plastic strain.



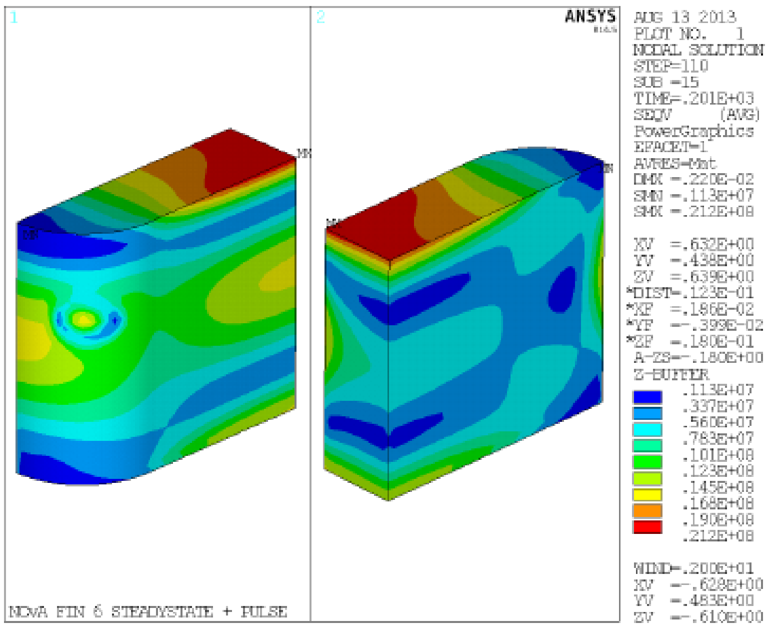
Evolution of Plastic Strain

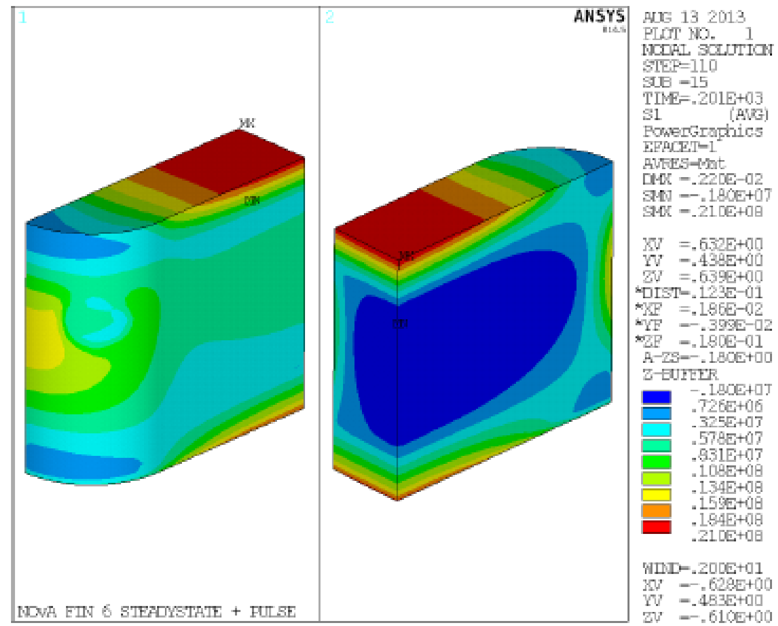


Plastic strain levels off after the four pulses. No ratcheting is evident.

Fin 6 Stresses - After First Cooldown

Left figure is Von-Mises stress, right is maximum principal stress.





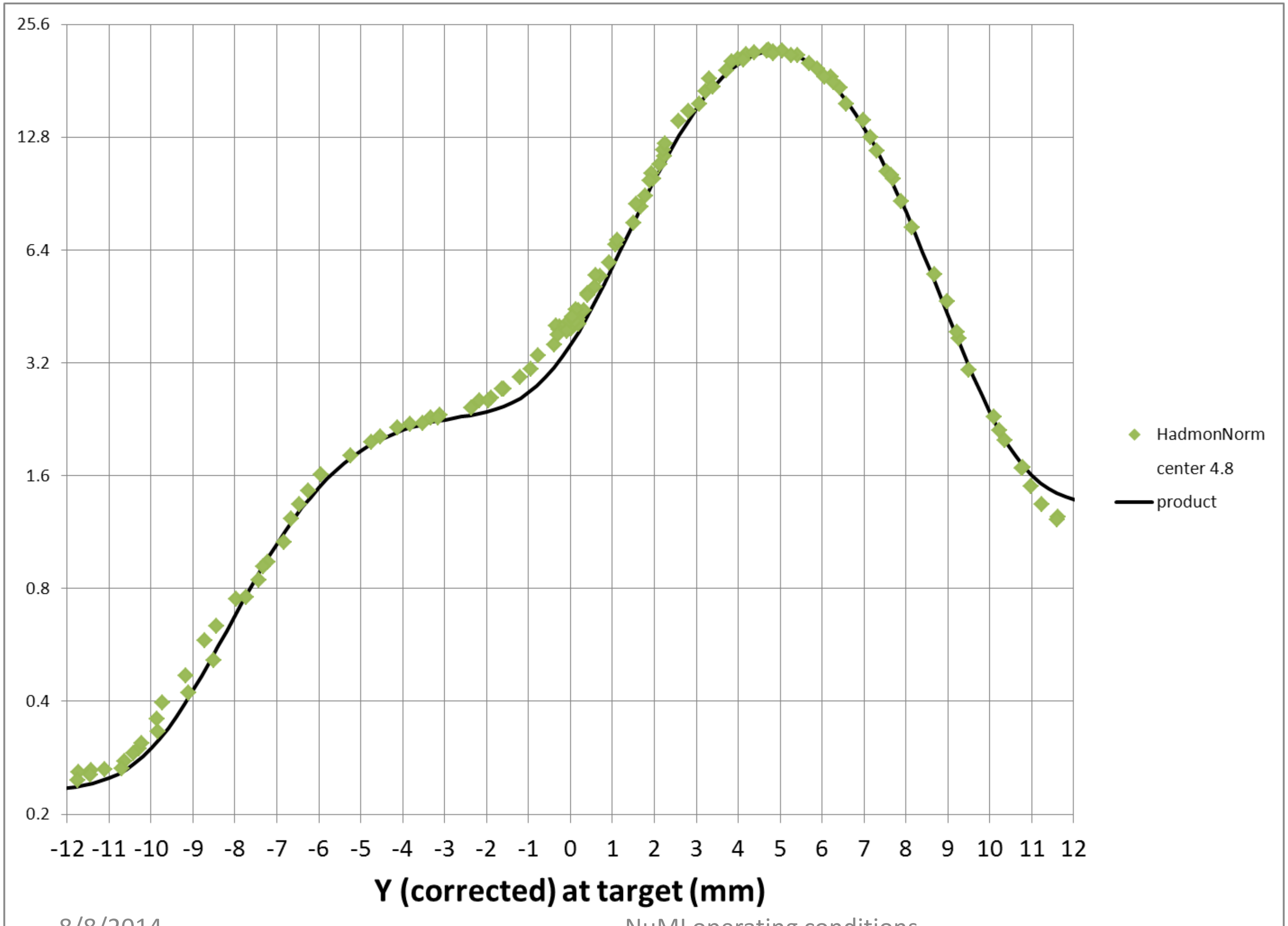
There is virtually no compressive pre-load in the beam spot, and a very small amount of pre-load in the area that has been plastically deformed.

Would someone mine old muon monitor data to see how well ratio of muon monitors showed NT-02 deterioration ?

- Laura Loiacono had plotted this for part of the NT-02 run, and got a good correlation, but much more data exists

- With higher power, radiation damage may (or may not) accumulate faster this run
- Especially interesting for LBNE design, does this technique really work ?

Vertical target scan using hadron monitor
"Fit" by eye with three cumulative gaussians, representing
target fin and two baffle edges, (amplitude = no. of int. lengths, tuned to plot)



Baffle at nominal

Target tip 0.4 mm low

Lack of target symmetry makes this hard to judge

Before smaller spot and target move